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CALIBRATION OF FIELD REFERENCE PANEL AND RADIOMETERS USED IN FIFE 1989

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INTRODUCTION

Remote sensing of the earth's surface features involves the measurement of reflected solar radiation and the interpretation of the data in biophysical terms. Reflected radiation is a function of the surface properties and incident solar irradiance. The amount of radiation reflected from a surface is compared to the amount of solar radiation received at the surface as a means of comparing information from different times of day as well as for different days of the year. Thus, it is imperative to calibrate the instruments used to measure the incoming and reflected radiation.

CALIBRATION OF FIELD REFERENCE PANEL

A good estimate of the amount of incoming radiation is important in order to calculate the reflective properties of a surface. Highly reflective reference surfaces are used to estimate the incoming radiation. These surfaces will have reflective properties dependent on the solar zenith angle (regardless of their construction). It is important to periodically characterize reflective reference surface properties as a function of solar zenith angle since dust, use and surface deterioration will change the reflective property. Once calibrated, reference surfaces can be used in the field to estimate the amount of incoming radiation with the assurance of valid reflectance calculations.

Field facilities were developed for the calibration of remote sensing field reference surfaces to be used in reflectance calculations. A goniometer was constructed based on an instrument designed and used by Ray D. Jackson (USDA Water Conservation Laboratory, Phoenix, Arizona) to develop a field panel calibration technique as outlined in Jackson et al. (1987). Instruments used to measure surface reflected radiation are used to calibrate the reference surface. An advantage to the use of these facilities is that the irradiance and instrument characteristics are the same as those under field situations. A disadvantage is that clear sky conditions are essential.

A 2'x 2' halon panel (Labsphere, Inc.) was used as a standard. Spectral directional-hemispherical reflectance factors, $\rho_\lambda(8°,2\pi)$, of the panel were characterized by the manufacturer and compared to a halon powder panel pressed according to NBS standards by R.D. Jackson in April, 1989. The field reference surface used in FIFE is a 4'x 4' halon panel (Lapsphere, Inc.). The calibration procedure uses the fact that the bidirectional reflectance factors $\rho_\lambda(\theta_s;\theta_v)$ are related to directional-hemispherical reflectance factors (a known quantity in the case of the pressed halon panel manufactured according to NBS standards and for the 2'x2' halon standard measured by the manufacturer). Since the instrument voltage response for a given waveband is proportional to the bidirectional reflectance factor we can say that the ratio of the instrument voltage responses measured over the field reference panel ($V_{f,k}$) and the standard surface ($V_{s,k}$) is equal to the ratio of the actual bidirectional reflectance factors measured over the field reference ($\rho_{f,k}$) and the standard surface ($\rho_{s,k}$) for each waveband, k, and at nadir for a particular solar zenith angle (θ_s). That is,

$$\frac{V_{f,k}(\theta)}{V_{s,k}(\theta)} = \frac{\rho_{f,k}(\theta)}{\rho_{s,k}(\theta)}$$

The goniometer permits the incident radiation to strike the panels at solar incidence angles ranging from 15-75° at approximately 10° intervals in a period scanning 10 minutes for each panel. Using the relationship between the ratios we can solve for the field reflectance panel bidirectional reflectance factors at nadir as a function of solar zenith angle for each waveband k, $\rho_{f,k}(\theta_i;0°)$. The field reference surface was calibrated in September (DOY 261) 1989 using MMR (S/N 114) and in March (DOY 261) 1990 using a SE590 (S/N 1571).

Reflectance factors as functions of solar incidence angle and wavelength as measured with the MMR are given in Table 1 and as measured with the SE590 are given in Figure 1.

Table 1

4'x4' molded halon field reference panel
reflectance factors as functions of solar incidence angle and wavelength
as measured with the MMR

Solar Zenith Angle	Band1	Band2	Band3	Band4	Band5	Band6	Band7
15	1.061	1.062	1.061	1.061	1.052	1.036	1.023
20	1.058	1.057	1.057	1.057	1.049	1.034	1.022
25	1.052	1.051	1.051	1.051	1.044	1.032	1.019
30	1.045	1.043	1.044	1.043	1.038	1.027	1.013
35	1.035	1.033	1.034	1.033	1.030	1.022	1.006
40	1.023	1.022	1.023	1.021	1.020	1.014	0.997
45	1.010	1.009	1.010	1.008	1.008	1.005	0.986
50	0.995	0.995	0.995	0.992	0.994	0.994	0.973
55	0.978	0.979	0.978	0.976	0.979	0.981	0.957
60	0.961	0.961	0.960	0.957	0.962	0.967	0.941
65	0.941	0.941	0.940	0.937	0.943	0.950	0.922
70	0.921	0.919	0.919	0.916	0.922	0.931	0.902
75	0.899	0.896	0.895	0.894	0.900	0.910	0.880

CALIBRATION OF THE RADIOMETERS

Temperature Sensitivity of the MMR and the SE590. The output of the MMR viewing a constant source can vary depending on the temperature of the instrument (Jackson and Robinson, 1985; Markham et al., 1988). The lead sulfide detectors, used in bands 5-7, are particularly vulnerable. The output variation as a function of ambient temperature of the SE590 is unknown. The sensitivities of the MMR and SE590 were quantified by measuring the instrument output when viewing a constant source as the ambient temperature was varied.

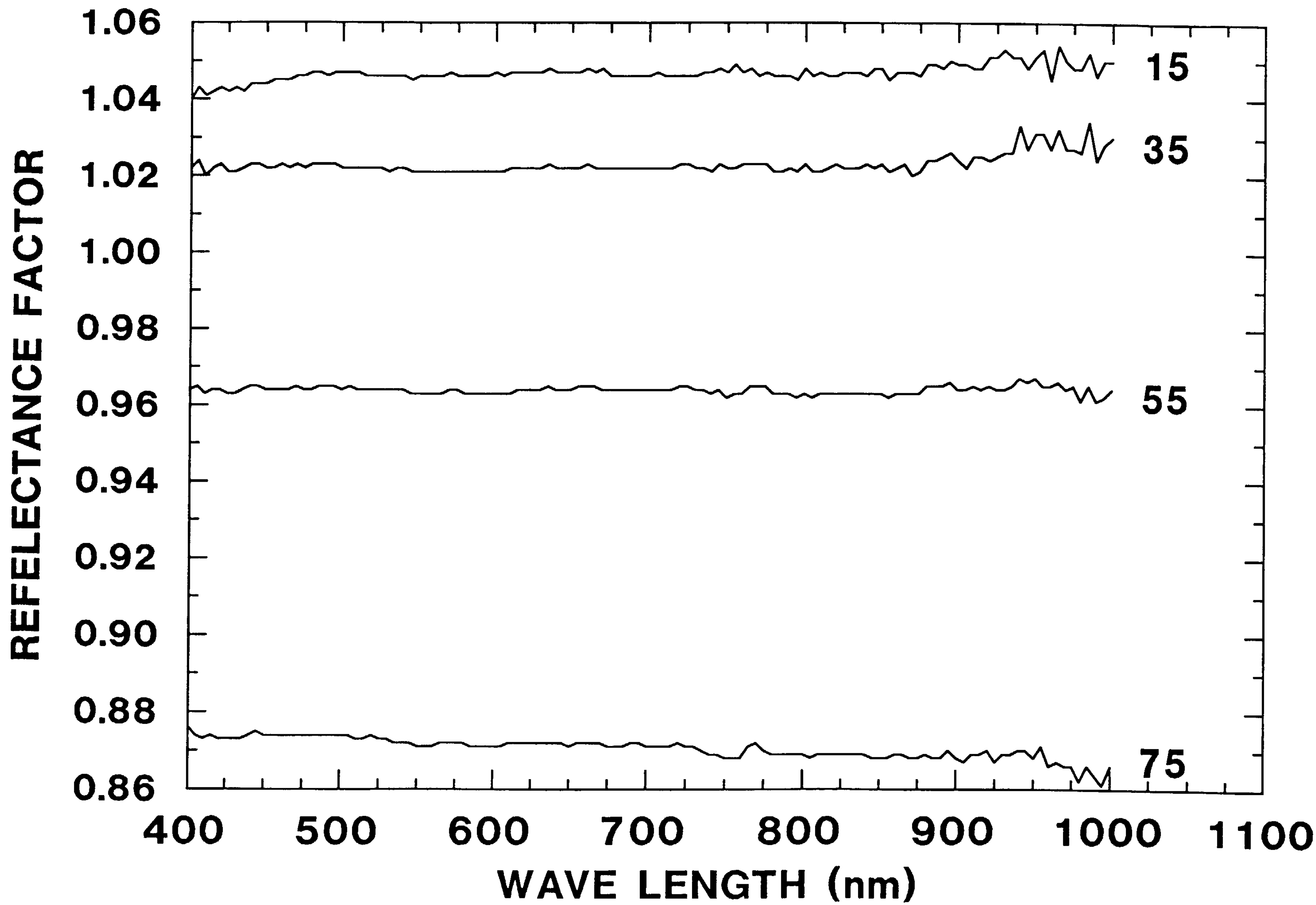

Figure 1. 4'x4' molded halon field reference panel reflectance factors as a function of solar incidence angle and wavelength as measured with the Spectron Engineering SE590 Spectroradiometer.

Output was monitored during FIFE'89 using the Kansas State University Evapotranspiration Laboratory environmental chamber at temperature settings ranging from 16 to 43.5°C at 5 to 7°C increments. The MMR and SE590 were placed in the chamber for several hours at each temperature setting so that the instruments could equilibrate to the ambient temperature before viewing the constant light source. A 30 cm integrating sphere illuminated with one and two lamp settings was used as a source. The different lamp settings were used to check the response at different radiant energy levels. The MMR response varied considerably in wavebands 5, 6 and 7 (Figure 2). Temperature sensitivity coefficients have been calculated by B. Markham according to the procedures outlined by Markham et al (1988). Error without correcting (given the range of temperatures in the calibration study) could be as great as 60 Wm^{-2} in band 5. Correction yields fairly consistent radiance measurements regardless of ambient temperature. (NOTE: these results are not an independent study of the accuracy of the correction, i.e., the correction was performed on the data from which correction coefficients were derived). The SE590 response varied beyond 0.850 μm (Figure 3). No other SE590 units were tested so that it is uncertain if the response is instrument specific or whether all units are temperature sensitive. Coefficients for the SE590 have not been computed, but results indicate that using measurements at wavelengths of 1.0 μm may result in discrepancies of approximately 50 $W\ m^{-2}$ if the instrument temperature varies from 16 to 43.5°C.

Estimation of Reflectance Measurement Errors. The possible errors associated in using a different instrument for the target than was used for the estimation of incoming radiation were quantified. The procedure involved 1) calculating canopy reflectance factors in which the reflected radiation from the reference panel and target were measured with the same instrument (MMR S/N 114), 2) calculating canopy reflectance factors as the ratio of reflected radiation

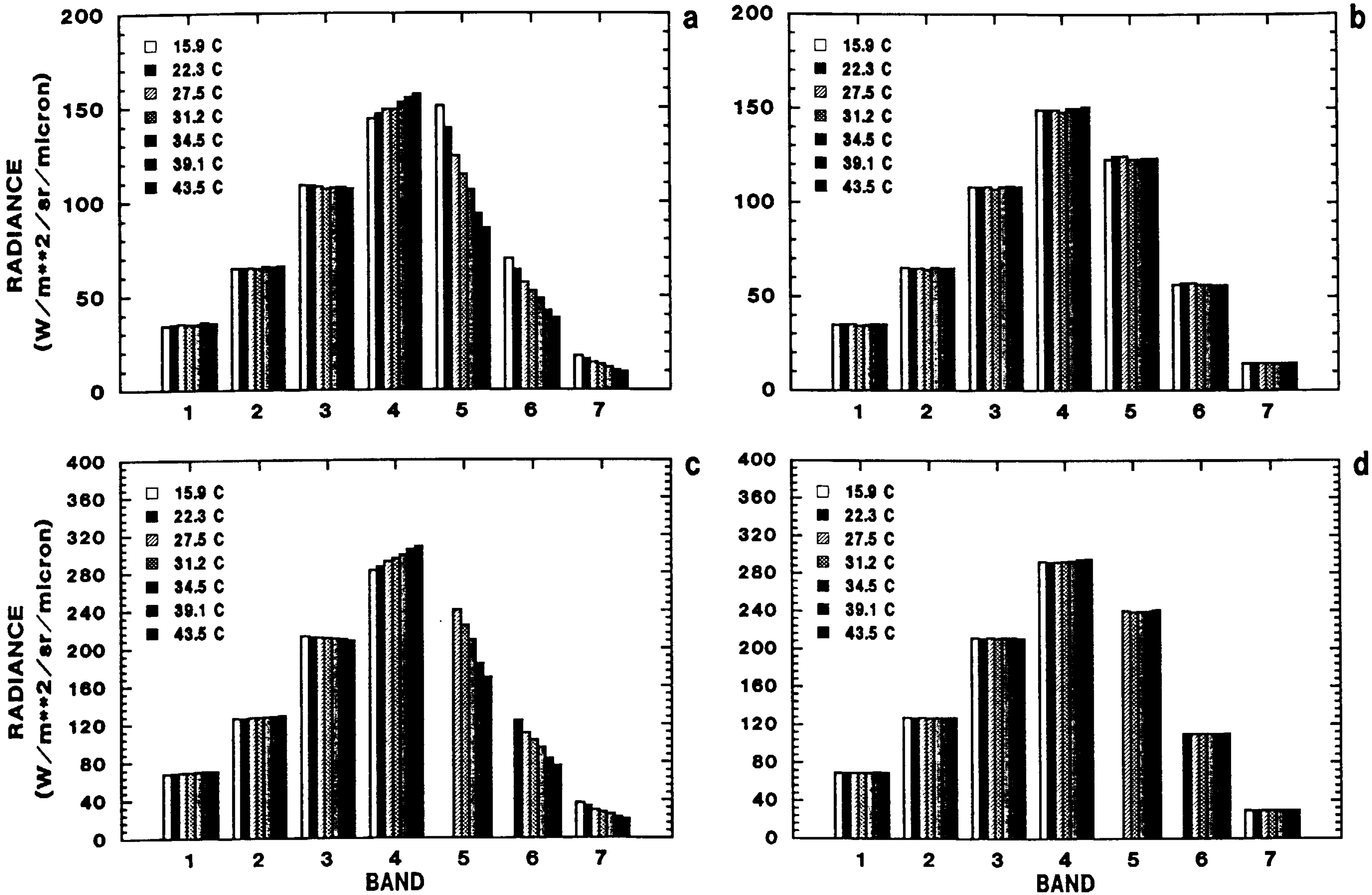

Figure 2. Output from a 30 cm integrating sphere as measured with a Barnes Modular Multiband Radiometer (MMR) (S/N 114) with low and high radiance settings as a function of ambient temperature: a) uncorrected low radiance output, b) corrected low radiance output, c) uncorrected high radiance output, and d) corrected high radiance output.

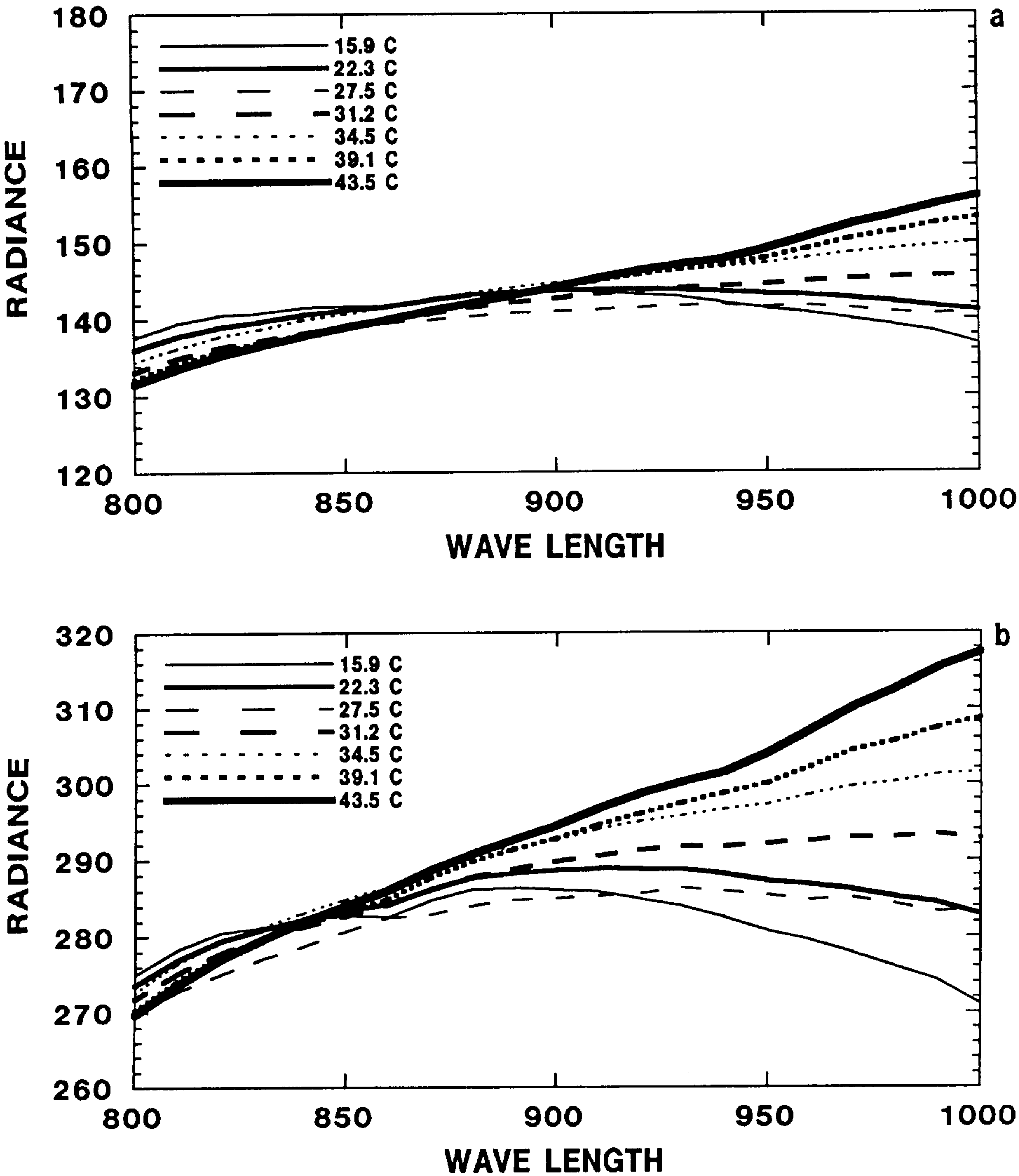

Figure 3. Output from a 30 cm integrating sphere as measured with a Spectron Engineering SE590 Spectroradiometer (S/N 1571) with low and high radiance settings as a function of ambient temperature: a) uncorrected low radiance output, and b) uncorrected high radiance output.

from the canopy (MMR S/N 114) to the reflected radiation from the same reference panel as in #1 measured by a different instrument (MMR S/N 111), and 3) calculating the root mean square error (RMSE) using measurement #1 as the "true" value. This was possible with the measurement procedure used in 1989. MMR S/N 111 was mounted over the reference panel and collected data every minute during the helicopter flights. MMR S/N 114, mounted on a portable mast, collected canopy reflected radiation data and periodically took measurements over the panel from which the incident radiation was interpolated following the method of Ranson et al., 1985.

Data collected on DOY 220 1989 was used. All instruments performed well with the highest "error" being approximately 1.5% (absolute) in wavebands 5 and 6 (Table 2).

Table 2

Root Mean Square Error from Comparison of Reflectance Factors Computed by Ratioing Canopy Reflectance output (MMR S/N 114) with panel output from two different MMR's (S/N 114 and S/N 111)

Waveband	RMSE (%)
1	0.06
2	0.04
3	0.02
4	0.46
5	1.27
6	1.48
7	0.38

Errors Associated with Leaf Optical Property Measurements. The transmittance of neutral density filters (Merle Groitt, Inc.) of known transmittance were measured with the NMLR mounted to a LI-COR Integrating Sphere. Neutral density filter transmittance values ranged from 1 to 56.5%, a value range typically encountered in leaf optical measurements. The RMSE was used to quantify the departure of the measured transmittance from the "true" transmittance value of the neutral density filters. (The filters were characterized using optics facilities at NASA Goddard in the fall of 1989). The NMLR has both the LI-COR standard light source as well as a specially adapted lamp which has a narrower beam. The beam was narrowed for use on the narrower grass leaves. Typically the leaves do not fill the entire sample port of the integrating sphere so that with the standard light source, an area larger than the leaf blade would be illuminated whereas with the narrowed beam of the altered light source only a portion of the leaf is illuminated.

Errors associated with leaf optical properties are approximately 0.5% within wavebands 1 through 4 while the errors are generally higher in the lead sulfide detector bands (bands 5-7), in particular, band 7 (Table 3). This error could be due to the temperature sensitivity of the detector (as in the MMR). However, the leaf radiometer is not equipped with a thermistor to indicate the temperature of the instrument which would permit correction of the response as is done with the MMR.

Table 3

Comparison of Measured Neutral Density Filter Transmittances with Calibrated Neutral Density Filter Values

	RMSE	
Waveband	Standard Light Source (%)	Narrow-beam Light Source (%)
1	0.5	0.8
2	0.4	0.5
3	0.4	0.5
4	0.5	0.5
5	1.0	2.5
6	0.6	1.4
7	2.9	6.8

Thermal Instrumentation Calibration. The thermal channel of MMRs S/N 111, 114 and 117 were calibrated at the USDA-ARS Water Conservation Laboratory in Phoenix, Arizona in early July 1989 against a variable blackbody source at a range of ambient temperatures. Correction coefficients were calculated by using the procedure as outlined in Markham et al. (1988). Temperatures calculated using the data from the calibration dataset and the derived coefficients at all ambient temperatures (i.e., not an independent dataset) show that there is scatter on the average of 0.6°C around the 1:1 line (Figure 4 a,b). Comparison of the results between MMR S/N 117, mounted on the helicopter, and S/N 114, mounted on the portable mast, indicate an average error of approximately 0.8°C when comparing the target temperature measured by the instruments of the same target (Figure 4c).

Everest Transducers were calibrated following the same procedures as with the MMR. A linear regression was applied to the data so that once corrected the measured values differed from the source value at most approximately 2°C at any particular ambient condition (Figure 5). Overall, instruments measured within 1°C of the source output after correction (Figure 6). Without the linear regression correction, measured values can differ from the source by approximately 4°C at any ambient temperature and overall by 2°C from the source output.

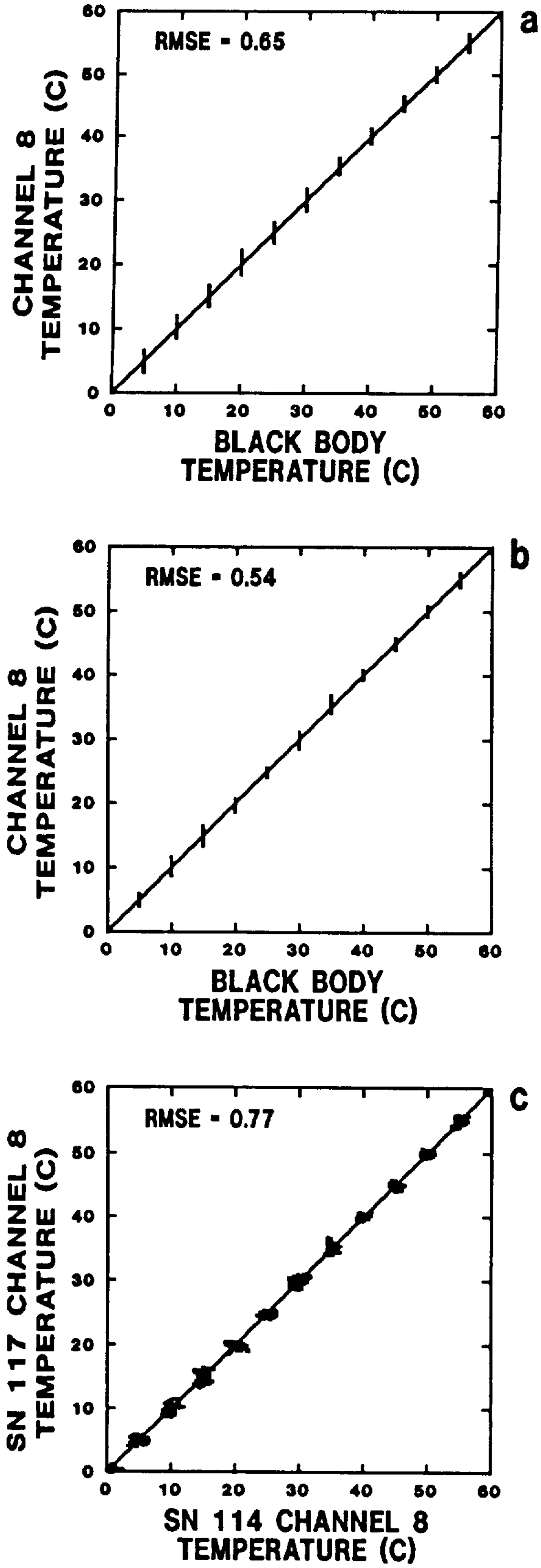

Figure 4. Barnes Modular Multiband Radiometer (MMR) thermal channel (band 8) response for a range of target temperatures under a range of ambient temperatures for a) S/N 114, b) S/N 117, and c) a comparison of response between S/N 114 and S/N 117.

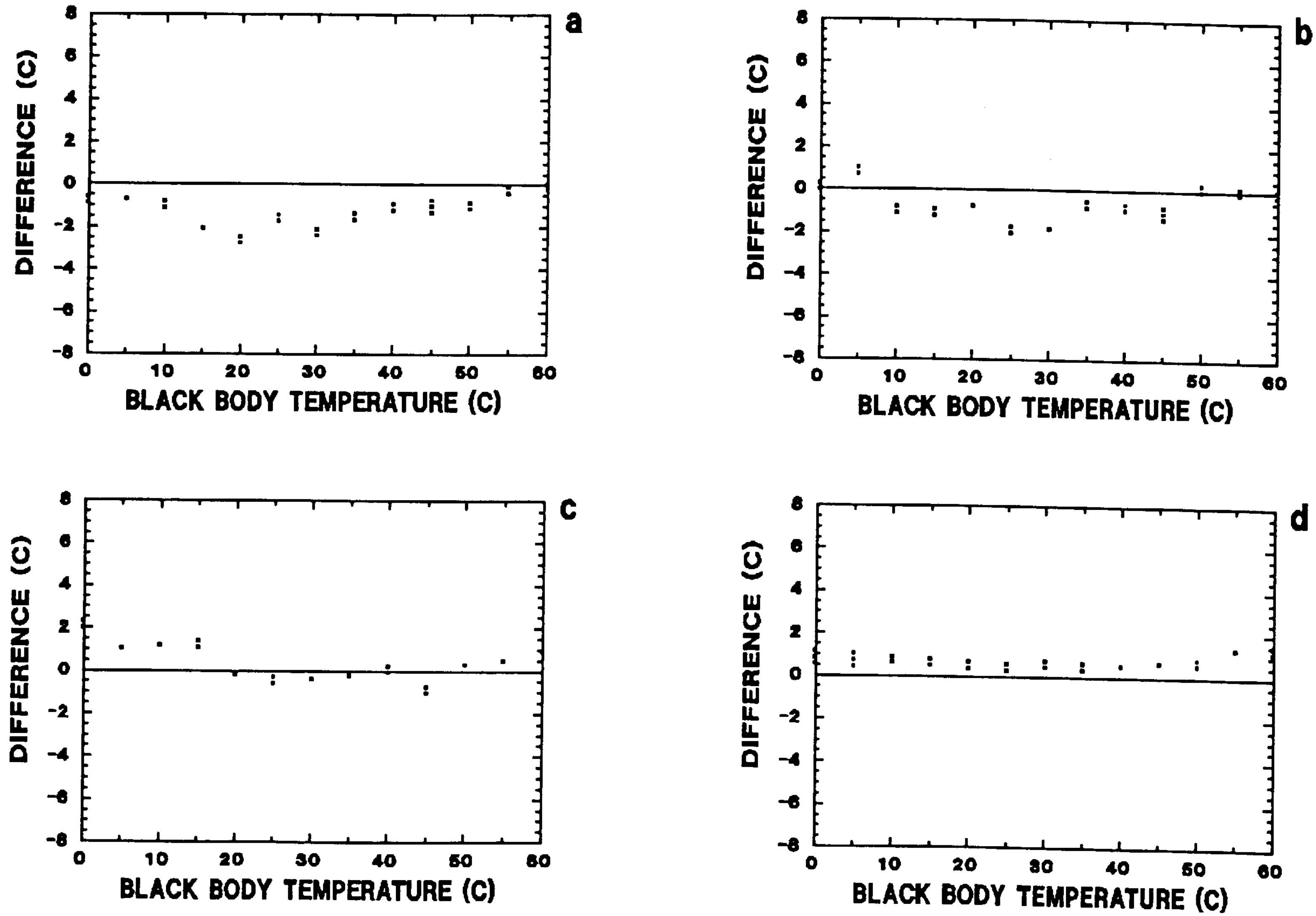

Figure 5. Everest Transducer (S/N 1031) differential response (measured response - known blackbody response) for a range of target temperatures at ambient temperatures: a) 15°C, b) 20°C, c) 30°C, and d) 40°C.

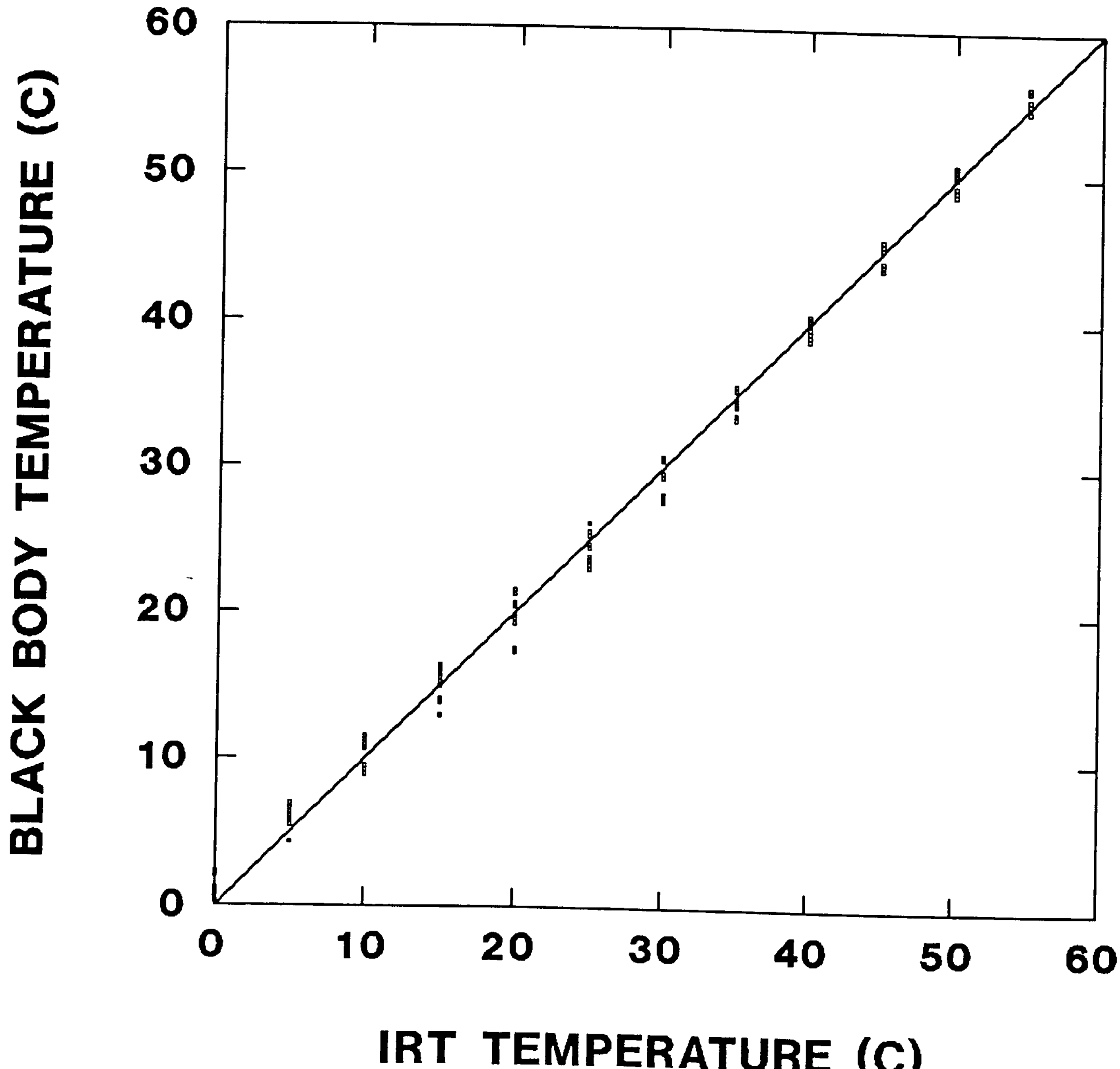

Figure 6. Everest Transducer (S/N 1031) temperature response for a range of target temperatures under a range of ambient temperatures.

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